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Geomorphological impacts of an extreme flood in SE Spain

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ABSTRACT

Long-term field studies in semiarid ephemeral streams are rare. These geomorphic data are essential for understanding the nature of the processes in order to develop modelling for risk assessments and management. An extreme flood event on 28 September 2012 affected the Murcia region of SE Spain, including long-tem monitoring sites on two fluvial systems in the Guadalentín basin, the Nogalte and Torrealvilla. Detailed morphological data were collected before and immediately after the event; and the amount of morphological change, erosion, and deposition have been related to peak flow conditions at the sites.

On the Nogalte channel, peak flow reached 2500 $m^3 s^{-1}$ at the downstream end of the catchment in less than 1 h. The event had a recurrence interval of >50 years based on rainfall records and damage to old irrigation structures. The major effect in the braided, gravel channel of the Nogalte was net aggradation, with massive deposition in large flat bars. The measured changes in bankfull capacity were highly correlated with most hydraulic variables. Net changes in cut-and-fill in cross sections on the Nogalte were highly related to peak discharge and stream power but much less so to measures of hydraulic force (velocity, shear stress, unit stream power). Relationships of amount of erosion to hydraulic variables were much weaker than for amount of deposition, which was largely scaled to channel size and flow energy. Changes on the Torrealvilla were much less than on the Nogalte, and net erosion occurred at all sites. Sites on the Nogalte channel in schist exhibited higher deposition than those of the Torrealvilla sites on marl for the same hydraulic values.

Overall, less morphological change took place in the extreme event on the Nogalte than predicted from some published hydraulic relations, probably reflecting the high sediment supply and the hydrological characteristics of the event. The results demonstrate the high degree of adjustment of these channels to the occasional, high magnitude, flash flood events and that such events need to be allowed for in management. The detailed quantitative evidence produced by these long-term monitoring sites provide valuable, rare data for modelling morphological response to flood events in ephemeral channels.

1. Introduction

In semiarid areas, flow in channels is ephemeral, with occasional flash floods of varying magnitude. Large flash floods can result in fatalities and in major damage to infrastructure (Barredo, 2007; Lumbroso and Gaume, 2012) so it is of major importance to assess and quantify effects for management purposes, hazard mapping, and planning in order that the danger can be minimised and that the effects can be allowed for (Poesen and Hooke, 1997). Hazards not only may be caused by inundation and the direct effects of the flowing water but also by physical impacts of sediment movement, erosion, and deposition, and by the associated destruction. Geomorphologically, flood events are when the main changes take place in channels, and one of the major questions is the role of large floods and their relative contribution to sediment flux and to landscape changes. The trajectories of channels and the role of floods in contributing to altering those trajectories need to be understood and feedback effects of altered morphology incorporated in flood modelling (Hooke, 2015). Data on effects of different flows are also needed to build predictive models of impacts of likely changes in flow regimes resulting from climate change and/or land use change (Hooke et al., 2005). Field data are required for model validation and to test principles and assumptions in models. Data are also needed to set the limits of uncertainty in any estimates and predictions. For all these reasons, documentation and measurement of the effects of major events is important, especially in ephemeral channels where such data are rare.

A major flash flood event occurred on 28 Sept 2012 in SE Spain, which resulted in 10 fatalities and much damage to infrastructure, including damage to bridges and roads, and much impact on agriculture (AON Benfield, 2012). It varied in magnitude and intensity across the region but is calculated from some hydrological parameters to be an extreme event on the European scale (Kirkby et al., 2013) and even on a world scale in terms of unit discharge (Thompson and Croke, 2013). This paper examines the morphological changes produced by the event in two channel systems by analysing measurements at sites that

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have been continuously monitored for morphological change since 1997 (Hooke, 2016), specifically for the purpose of quantifying effects on morphology, sediment, and vegetation of different size flows. Data capturing detailed measurements of impacts of extreme events are rare, especially for such flash floods in semiarid environments, and difficult to collect even when instrumentation is present (Coppus and Imeson, 2002). It is especially rare to have before and after measurements of detailed topography and channel characteristics and at a number of sites, as in this case. The amount and type of change is analysed in relation to hydraulics of the flow event and the morphological characteristics of the sites. Nardi and Rinaldi (2015) remarked that few examples of such relationships from flood events have been published.

Geomorphological impacts of case studies of high magnitude floods have been recorded, and forces and dynamics of the events analysed recently (e.g., Fuller, 2008; Hauer and Habersack, 2009; Milan, 2012; Dean and Schmidt, 2013; Thompson and Croke, 2013) and in many (now classic) case studies from the 1970s and 1980s (reviewed in Hooke, 2015), but these are mainly in humid areas, on perennially flowing streams. Many are in upland environments and involve effects on slope instability and sediment influx as well as on channels. Studies of individual events in drylands and the Mediterranean region include those of Harvey (1984) in SE Spain, on a channel of similar characteristics to one studied here, and various studies elsewhere in Spain (e.g., Ortega and Garzón Heydt, 2009), on the Magra River in Tuscany, Italy (Nardi and Rinaldi, 2015), in southern France (Arnaud-Fasetta et al., 1993; Wainwright, 1996), in Israel (Schick and Lekach, 1987; Greenbaum and Bergman, 2006; Grodek et al., 2012), and in SW USA (Huckleberry, 1994). Most of these studies do not have prior morphological data. Hooke and Mant (2000) measured the effects of a flood in 1997 at the same sites as analysed here. Conesa-García (1995) previously assessed the effects of different size events on one of these same channels. Some measurements of processes in flood events, hydraulics of sediment transport and sediment dynamics, have been made at instrumented sites in dryland areas, particularly in Israel (Laronne and Reid, 1993; Schick and Lekach, 1993; Reid et al., 1995; Cohen et al., 2010) and at Walnut Gulch in Arizona (Powell et al., 2007; Nichols et al., 2008), but also in Spain (Martín-Vide et al., 1999; Batalla et al., 2005); and measurement after events has been used in modelling competence, capacity, and flux (Billi, 2008; Thompson and Croke, 2013). Composite data on multiple extreme flood events were compiled by Baker and Costa (1987), Kochel (1988), Newson (1989), Miller (1990), Magilligan (1992), and Costa and O'Connor (1995) in which thresholds and extremes were identified and are commonly used as benchmarks for assessing impacts. Prior morphological data of sufficient resolution are now becoming available through LiDAR surveys and laser scanning, as exemplified in recent studies; for example, Hauer and Habersack (2009) analysed changes in long reaches of channel where repeat terrestrial laser scanner surveys were available, and Nardi and Rinaldi (2015) used LiDAR in combination with before- and after-event aerial photographs. Various aspects of a large, infrequent flood event in Queensland, Australia, have recently been investigated by Croke and her team (Croke et al., 2013; Grove et al., 2013; Thompson and Croke, 2013; Thompson et al., 2013) using LiDAR.

A major theme in the geomorphological literature is that of magnitude-frequency of floods and the relative morphological and sedimentological effects of different events. Various conceptual frameworks are available for assessing the contribution in the longer term, notably through sediment transport as a measure of amount of geomorphic work done (Wolman and Miller, 1960), geomorphic effectiveness as a measure of change in landforms (Wolman and Gerson, 1978), and effects of thresholds within the system that may produce sudden and large changes, or even metamorphosis (Schumm, 1973, 1979). Flood impacts have been analysed in relation to various measures of flood characteristics, including unit stream power (Magilligan, 1992), competence (Jansen, 2006), and duration (Miller, 1990). LiDAR availability is extending the spatial scale of analyses of flood impacts (e.g., Thompson and Croke, 2013). The importance of the physical setting and spatial relations of reaches in determining flood impact is increasingly demonstrated by such evidence and by comparison between morphologically contrasting reaches, particularly confined and unconfined reaches (e.g., Cenderelli and Wohl, 2003). Documentation of impacts of extreme events has shown that they vary widely with magnitude and other factors and that similar size floods can have different effects at different times in the same location and that very different size floods can have similar effects, depending on the state of the system and the flood characteristics (Hooke, 2015).

Much data have been published on flood-generating conditions and identifying upper limits of rainfall effects to feed into prediction and forecasting models. These are particularly important for incorporating into assessments of impacts of future climate change and land use scenarios, both of which are predicted to change markedly in the future in SE Spain (Herrera et al., 2010; Machado et al., 2011). Most scenarios envisage an increase in desertification and therefore in runoff and soil erosion. Much flood research focuses on the frequency and timing of flooding and on the conditions generating the floods; a major EU project, HYDRATE (Gaume et al., 2009), has compiled much hydrological and climatological data on extreme events. Extents of inundation and associated hazards are relatively well documented, and much of the effort in the flood arena is now on producing better predictive models of occurrence and impacts as a basis for flood risk management. A major theme within this work is the documentation and modelling of connectivity down the river system at a range of scales and between channel and floodplain (Thompson and Croke, 2013; Trigg et al., 2013; Reaney et al., 2014). However, much more evidence and quantification of type, amounts, and distributions of channel changes and physical impacts are needed to assess the patterns, variability, and uncertainty for use in modelling and prediction. Flood modelling is still a long way from incorporating feedback effects of morphological change (Wong et al., 2015).

The aims of this paper are (i) to quantify the physical impacts, amounts and scale of erosion and deposition and their distribution in an extreme event on one channel, and in a moderately large event on another channel, as measured on monitored reaches; (ii) to analyse the impacts in relation to the event peak flow hydraulics and the channel morphology in order to understand the controls and effects of conditions; and (iii) to compare these results to other published flood data.

2. Regional context and sites

The study area is located in the Guadalentín basin in SE Spain (Fig. 1). Monitored reaches were established in 1996/7 under the EU MEDALUS project (Hooke and Mant, 2015) specifically to test and validate a model of flood impacts and sequences of conditions that was being developed (Brookes et al., 2000; Hooke et al., 2005) because very little morphological change data existed for those or similar channels, nor data on sedimentological changes or interactions with vegetation and feedback on morphology, with which to validate the model. The region is semiarid with ~300 mm rainfall average. Three reaches, in the upper, middle, and lower parts of each of three channel systems were set up in 1996; these are (from south to north) the Nogalte, Torrealvilla (Fig. 1), and the Salada, near Murcia (Hooke, 2007). These were selected because of differing bedrock (Nogalte schist, others marl) and to provide a range of morphology, sediment, and vegetation conditions (Table 1). The sites were located in different parts of the catchment also to increase the likelihood of measuring flows because many flows are highly localised and do not persist down the channel (Hooke and Mant, 2002b). The sites are all within the upland area, mostly in well-defined valleys (Fig. 2). The area is mainly rural with dryland agriculture, dominated now by almond and olive cultivation. Irrigated agriculture occurs in parts of the area. Much of the slopes are afforested as part of the policy of flood control, and many check dams have been built along the water courses, particularly in the headwaters. Some land is